INTERNATIONAL SCIENTIFIC JOURNAL
GEOGRAPHICA PANNONICA
Volume 28, Issue 4, 284–293 (December 2024)
Journal homepage: http://www.dgt.uns.ac.rs/en/homepage/pannonica/

Mortality Risk during Heatwaves: an Evaluation of Effects by Heatwaves Characteristics in Serbia

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KEYWORDS

- heat
- heat-health risk
- DLNM
- mortality
- Serbia

ABSTRACT

Extreme temperatures and heatwaves are recognized as one of the deadliest weather-related hazards. The first of its kind in the Balkans region, this study explores the effects of heatwave timing, duration, and intensity on mortality in Serbia. Using daily all-cause mortality data and mean temperature, a distributed lag non-linear model (DLNM) evaluates the heat-mortality response for each city during the warm season (May to September) for the period 2000-2015 for Belgrade, Novi Sad and Niš. Results indicate that longer heatwaves generally have a greater impact on mortality, regardless of when they occur in the warm season. When comparing warm and extremely warm days, relative risk (RR) increases with intensity, and RRs are higher for earlier season heatwaves Extremely warm, early season heatwaves show significantly high RR in all three cities, respectively, for Belgrade 1.37 (95% CI: 125, 1.5), for Novi Sad 1.27 (95% CI: 1.08, 1.5), and for Niš 1.47 (95% CI: 1.15, 1.87). The findings draw attention to how different heat events modify the health response in Serbia. Stakeholders who work to improve resilience to heat hazards may consider the development of an early warning heat system and a strengthening of local and regional outreach efforts designed to reduce adverse health outcomes.

Introduction

The World Health Organization (WHO) recognizes climate change as one of the greatest challenges of the 21st century and an important public health threat (WHO, 2023; van Daalen et al., 2024). Adverse health outcomes such as mortality and hospitalization are impacted by a variety of complex environmental factors, but thermal exposure is one of the most pronounced (Ballester et al., 2023; IPCC, 2022). Due to anthropogenic climate change, heatwaves have increased in frequency, intensity, and duration (Russo et al., 2014; Mitchell et al., 2019; Perkins-Kirkpatrick & Lewis, 2020; IPCC, 2022). Since the begining of 21st century, Europe has experienced several intense heatwaves, including in 2003 when over 70,000 heat-related deaths occurred (Watts et al., 2018). Studies also report an increase in mortality during the 2015 and 2019 summers (Vicedo-Cabrera et al., 2016; Urban et al., 2017; Arsenović et al., 2019; Mitchell et al., 2019; Blazejczyk et al., 2022). Characterized by record-breaking high temperatures (May – September), Bal-

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doi: 10.5937/gp28-52729
Received: August 13, 2024| Revised: December 3, 2024| Accepted: December 17, 2024

lester et al. (2023) estimated more than 60,000 heat-related deaths in Europe during the 2022 warm season.

When analyzing the impact on human health, various heatwaves defintions exist, characterized by duration, intensity, and thermal or atmospheric metric (Anderson & Bell, 2011; D'Ippoliti et al., 2010; Xu et al., 2016; Royé et al., 2020; Awasthi et al., 2022; Yadav et al., 2023). Some studies consider the role of seasonality and heatwave timing (Andreson & Bell, 2010; Sheridan & Lin, 2014; Sun et al., 2020; Alari et al., 2023). Both heatwave length and duration influence health response. A systematic review showed that in heat-related mortality heatwave intensity played a more significant role compared to heatwave duration (Xu et al., 2018; Xu et al., 2016). Results for nine European cities indicate that mortality increases during the heatwaves ranged from 7.6% to 33.6%, depending on geographic location, and this increase was up to three times more pronounced during periods of long lasting and high intensity heatwaves (D'Ippoliti et al., 2010). In Brazil, Silveira et al. (2023) found heatwave intensity to be a greater risk factor than duration.

Evaluating 43 U.S. cities, elevated mortality risk was found for more intense or longer-lasting heatwaves, and mortality risk was higher for early-season events (Anderson & Bell, 2011). In a study of the four largest cities in Spain (1990-2015), Royé et al. (2020) showed a non-linear, J-shaped curve between heateave intensity and mortality. Various studies indicate an acute relationship between human response and heat, lagging heatwave impacts 1-3 days following a heat event (Donaldson et al., 2003; Arbuthnott & Hajat, 2017; Royé et al., 2020). Alarie et al. (2023) found a relationship between seasonal timing and cardiovascular and respiratory mortality in France. While the results indicate a larger influence of later-seasonal events, the results were heavily influenced by the 2003 event. By removing the outlier, early summer heat events showed a greater impact on mortality.

Overall, a lack of studies exist evaluating heatwave characteristics and the relationship to human health outcomes in Central and Eastern Europe, including Serbia (Zaninović & Matzarakis, 2014; Výberči et al., 2015; Petkova et al., 2021; Winklmayr et al., 2022; Ascione et al., 2022; Arsenović et al. 2019; Arsenović et al., 2023; Antonescu et al., 2023). Until now, limited number of studies examined heatwave and high temperature impact on health outcomes in Serbia (Bogdanović et al., 2013; Stanojević et al., 2014; Bijelović et al., 2017; Savić et al., 2018; Arsenović et al., 2019; Arsenović et al., 2022; Savić et al., 2023). Using the three largest cities in Serbia (Belgrade, Novi Sad, and Niš), this research is the first to comprehensively evaluate how mortality risk changes based on different heatwave characteristics in Serbia. By considering how heatwave duration, intensity, and seasonal timing influences mortality outcomes, the results of this research may also be used to better inform stakeholders who aim to reduce adverse health outcomes and improve resilience to future heat events in Serbia.

Data and Methods

Study Area

The study region includes three administrative units in Serbia: the Belgrade area, the Novi Sad City and the Niš City (Figure 1). Belgrade, Novi Sad and Niš are the most populated cities in country, and in 2015, these locations represented 32.0% of Serbia's total population. Total population in Belgrade exceeds 1.5 million people, and the other two cities (Novi Sad and Niš) range between 250,000 to 350,000 residents (Table 1).

Table 1. Descriptive data about administrative organization and total number of urban and rural population in censuses 2002 and 2011, and estimation for 2015, in three cities, Serbia

Area	Administrative organization[A]	Area[A] (in km²)	2002[B]		2011[B]		2015[C]	
			Urban	Rural	Urban	Rural	Urban	Rural
Belgrade area	17 municipalities	3226	1281801	294323	1344844	314596	1369401	310494
City of Novi Sad	2 municipalities	699	235165	64129	277522	64103	286546	64384
City of Niš	5 municipalities	596	178161	72357	187544	72693	186222	71661

Source: Republički zavod za statistiku, 2003; Republički zavod za statistiku, 2012a; Republički zavod za statistiku, 2012b; Online database[D]

[A] *According to the data in 2011*
[B] *Census data*
[C] *Estimation by Statistical Office of the Republic of Serbia*
[D] *https://data.stat.gov.rs/?caller=SDDB*

Figure 1. Map of study area with marked location of Belgrade, Novi Sad and Niš

Mortality and Meteorological Data

All-cause daily mortality data (ICD-10, code A00-U85) were provided by the Statistical Office of the Republic of Serbia (SORS) from 2000 to 2015. Researchers compiled the data for the three largest areas (cities) in Serbia: Belgrade, Novi Sad and Niš. Temperature data (°C) were provided by the Official Meteorological Yearbooks, available on the Republic Hydrometeorological Service of Serbia (RHMSS) website (https://www.hidmet.gov.rs). The data includes air temperature observations at 0700 (morning), 1400 (midday), and 2100 (evening) time periods. Aggregating these data, average daily air temperatures were calculated for each of the three cities for the warm season (May – September) for the period 2000–2015.

While various heatwave definitions exist (Robinson, 2001; McCarthy et al., 2019; Faye et al., 2021; Ventura et al., 2023), the RHMSS delineates two heatwave thresholds (RHMZS 2023). *Warm days* are defined as days where the daily air temperature exceeds the 91st annual percentile; *Extremely Warm days* are based on the 98th percentile. Using daily air temperature data, percentiles were calculated for each city and used to define warm and extremely warm days over the 16-year period (Table 2). Since the metrics are based on local climatology, the heatwaves incorporate a spatial variability rather than a nation-wide absolute threshold. A heatwave metrics in Belgrade is not the same as Novi Sad.

To compare the impact of heatwaves on mortality, heatwaves (HW) are subdivided to account for duration (short and long) and seasonal (early and late) events taking place from May - September. Short heatwaves (HW_{Short}) were periods where the daily mean air temperature exceeded the 91st or 98th percentile for one or two days. Long events (HW_{Long}) include days when the temperature threshold exceeded these thresholds but persisted for more than 2 days. This study included a 5-month warm season to account for early and late season heat events that may occur outside of the traditional meteorological summer. Early summer events (HW_{early}) occurred between 1 May - 14 July while 15 July to 30 September represented late summer (HW_{Late}). Similar methodological approaches have been used in the past (Allen & Sheridan, 2018).

Table 2. Percentile thresholds used to define *Warm* and *Extremely Warm* Heatwave (HW) days (°C)

Area	91st	98th
Belgrade	25.4	29.2
Nis	24.5	28.2
Novi Sad	23.8	27.2

Statistical analysis

To assess the heat-health effects, researchers employed a distributed lag non-linear model (DLNM). Common in public health research (Gasparrini et al., 2011; Armstrong, 2006; Gasparrini & Armstrong, 2011; Silveira et al., 2023; Boudreault et al., 2024), the DLNM is available as a package in R and evaluates both the non-linear exposure-response and delayed effects with time.

The model uses a quasi-Poisson regression to model the daily counts of deaths as a function of
(Equation 1):

$HW = 1$ *if heatwave exists*

$Y_{subset} \sim quasi\ poisson(HW)$

$$Log(HW) = \alpha + S\,(Time_{Year},\ var.df = 4) + S\,(Time_{JulianDay};\ 7{\times}15) + DOW$$

Where *HW* is a binary representation of a heatwave day, Y_{subset} is the observed daily mortality, α is the intercept, $Time_{Year}$ represents the long-term trend, $Time_{JulianDay}$ represents seasonal trends, and *DOW* was a dummy variable representing day of week (Equation 1). Confounders accounted for the seasonal variability in daily mortality, year, and day of week. *S* is the natural cubic spline function whereby *var.df* is the degree of freedom (df) for each variable. Four degrees of freedom were assigned to the long-term trend line while 7 df/year were used to identify the seasonality curve. These metrics are consistent with prior work (Allen & Sheridan, 2018).

The study used a 7-day lag model to account for the acute response of heat. Various lags were considered (3-, 5-, 7-, 10-, 14-day), yet the differences in results were generally minimal. Mean, maximum, and minimum relative risk were assessed. Statistical significance was based upon the 95% confidence intervals whereby if the minimum relative risk value was greater than 1.0, significance was assigned to the value. DLNM computed relative risk values for each category, and each HW category was independently analyzed: HW_{Early}, HW_{Late}, HW_{Shor}t, HW_{Long}, and all HW days. For example, all HW_{Early} days were compared against all non-HW days. The model used quasi-Poisson regression to determine the daily counts of deaths as a function of HW. Relative risk (RR) values were computed based upon DLNM iterations for each of the classifications.

Results

Summary statistics show differential HW characteristics across each of the three cities (Table 3). On average, at least 33 heatwave days occurred in each city, with the largest number of warm days (537) occurring in Niš. Across the 16-years, each city experienced averaged at least 7 extremely warm days per year. With 51 total, Belgrade recorded the most extremely warm days. Across the three cities, heatwaves varied in terms of intensity, duration, and seasonal timing. Anaysis in this study shows that longer and more intense HW were more frequent in Belgrade and Novi Sad.

Given the city's geographic location, it is no surprise the highest T_{avg} took place in Belgrade. Niš is situated in the southeast mountainous region while Novi Sad is further north and not as sprawling, thus perhaps not as influenced by the urban heat island as Belgrade. On average, locations experienced approximately 35 warm days per year- and 8 extremely warm days per year.

Average mortality was higher during extremely warm days when compared with warm days. For example, four additional people died on average in Belgrade during higher-threshold heatwave events. Statistical relationships are limited by the population size, but this result of warmer events is supported by previous research (Alarie et al., 2023; Anderson & Bell, 2011; Allen & Sheridan, 2018).

Table 4 shows the relative risk (RR) between different HW characteristics. All three cities showed significant, elevated risk associated with HW_{early}, regardless of the intensity metric. The highest RR was found in Niš and associated with early season, extremely warm days (RR: 1.47; 95% CI: 1.15, 1.87). While elevated risk was still found for late-season events, only Belgrade and Novi Sad showed significant results. Generally, mortality risk was higher under extremely warm days when compared to warm days or non-heatwave days. Comparing all heatwave iterations, higher RR was found for Belgrade and Novi Sad; both cit-

Table 3. HW characteristics, with average daily temperature (T_{avg}, in °C), average daily mortality (M_{avg}), and total heatwave days for Belgrade, Novi Sad, and Niš, 2000 - 2015.

HW timing/duration	HW intensity	Belgrade			Novi Sad			Niš		
		T_{avg}	M_{avg}	Total HW Days	T_{avg}	M_{avg}	Total Days	T_{avg}	M_{avg}	Total Days
HW_{early}	Warm	27.60	48	234	26.04	11	233	26.71	6	209
	Extremely Warm	30.20	52	45	28.25	12	56	29.15	6	45
HW_{late}	Warm	28.03	46	297	26.02	10	300	26.73	5	328
	Extremely Warm	30.50	51	83	28.32	12	70	29.38	6	73
HW_{short}	Warm	27.04	44	265	25.34	10	265	25.90	5	245
	Extremely Warm	30.18	50	91	28.07	11	87	29.13	6	84
HW_{long}	Warm	28.61	49	268	26.69	11	269	27.40	5	294
	Extremely Warm	30.94	54	37	28.77	14	39	29.70	6	34
All	Warm	27.84	47	531	26.03	11	533	26.72	5	537
	Extremely Warm	30.40	51	128	28.29	12	126	29.29	6	118

Table 4. Effects of heatwaves on mortality for different heatwave characteristics (mean RR using a 7-day lag) in Belgrade, Novi Sad and Niš, 2000-2015.

Timing/Duration	Intensity	Belgrade	Novi Sad	Niš
HW_{early}	Warm	1.21 (1.16, 1.26)	1.21 (1.12, 1.31)	1.19 (1.06, 1.34)
	Extremely Warm	1.37 (1.25, 1.5)	1.27 (1.08, 1.5)	1.47 (1.15, 1.87)
HW_{late}	Warm	1.16 (1.11, 1.2)	1.15 (1.07, 1.24)	1.01 (0.91, 1.11)
	Extremely Warm	1.27 (1.19, 1.37)	1.33 (1.15, 1.55)	1.01 (0.81, 1.25)
HW_{short}	Warm	1.02 (0.96, 1.08)	0.94 (0.83, 1.06)	1.07 (0.89, 1.29)
	Extremely Warm	1.19 (1.08, 1.31)	1.03 (0.84, 1.26)	1.04 (0.8, 1.36)
HW_{long}	Warm	1.22 (1.18, 1.27)	1.30 (1.21, 1.4)	1.09 (0.98, 1.21)
	Extremely Warm	1.43 (1.29, 1.59)	1.57 (1.29, 1.93)	1.31 (0.97, 1.76)
All	Warm	1.18 (1.14, 1.22)	1.18 (1.11, 1.25)	1.08 (0.99, 1.17)
	Extremely Warm	1.31 (1.24, 1.39)	1.31 (1.16, 1.47)	1.17(0.99, 1.39)

ies are located more north and likely impacted by population size available for robust statistical analysis. Different methodological approaches are needed to explore non-urban heat-health relationships (Allen et al. 2024).

When exploring the role of HW duration, HW_{long} showed greater RR compared to HW_{short}. Results in Belgrade and Novi Sad were significant, suggesting longer-lasting HW had a greater impact on mortality risk. A greater RR associated with long-lasting, extremely warm days was found compared to warm days or non-heatwave days. When comparing all HW days, extremely warm days showed a higher risk than the lower threshold of warm days.

Discussion

This is the first study to explore how HW duration, intensity, and seasonal timing modifies the mortality relationship in Serbia. Results indicate a few important findings. First, long-lasting heatwaves typically have a greater impact on mortality, regardless of when they occur in the warm season. Longer-lasting heatwaves show elevated RRs when compared to both shorter and non-heatwave days. HW duration has important role in mortality risk (Borrell et al., 2006; Sheridan & Lin, 2014; Steul et al., 2018; Allen & Sheridan, 2018), and according to some research, duration of HW is better signal for excess mortality than temperature alone (Steul et al., 2018). Variations do exist, however, as Guo et al. (2017) showed intensity to have a more significant role that duration.

This research found early season HW to have a greater impact on mortality that later-season HW. Studies show heatwaves occurring earlier in the warm season result in greater mortality risk (Díaz et al., 2002; Anderson & Bell, 2011; Sheridan & Linn, 2014; Smith et al., 2014; Xu et al., 2018). Various factors including seasonal acclimation play a role in such results. Throughout the warm season, heat-related risk may decrease because of seasonal acclimation or mortality harvesting, although prolonged heat days still had a greater influence on mortality (IPCC, 2022; Allen & Sheridan, 2018). Sun et al. (2020) found that mortality risk during the first heatwave of the season increased by 16.3%, while during the each subsequent heatwave, risk decreased. While other studies indicate mixed results (Alarie et al., 2023), results of this study indicate higher mortality risk during early-season HW.

Finally, this study identified association between HW intensity and mortality, suggesting that population vulnerability is particularly pronounced during the extremely warm days. Intensity modified the temperature-mortality relationship with extremely warm days generally showing higher RR when compared to warm HW days. In Spain, Roye et al. (2020) found a strong relationship between mortality and the effects of heatwave intensity, with particularly high impact on the same day and 1-3 days following heatwave. Acute mortality response is well-documented within heat-health literature (Meade et al., 2020; Liu et al., 2022), and short-term mortality harvesting may explain some of the results.

While variability exists across the 3 Serbian cities, the results are generally consistent in that longer-lasting, earlier occurring, and more extreme heatwave show the greatest mortality response. Heatwave characteristics matter in the context of heat-health response and how communities may prepare for future heatwaves. As heatwaves become more frequent and extreme (Perkins-Kirkpatrick & Lewis, 2020; IPCC, 2022), how communities prepare for 21st century heatwaves must consider changes in HW characteristics. A heatwave in 2024 is not the same as a heatwave in 2003, nor are Belgrade heatwaves the same as those in Novi Sad. Geography matters. Population demographics vary. Community networks designed to reduce heat-related mortality differ across scales. The strengthening of local and national multi-sectoral partnerships (public health, emergency response, weather forecasting, governance and policy) is needed to reduce the heat-health burden. Improved heat communication, policies designed to protect human health, the creation of new and protection of old green space, and various other strategies are noted elsewhere (Stanojević et al., 2014; Bijelović et al., 2017; Tong & Ebi, 2019; Muccione et al., 2024; Turner et al., 2022; Keith & Meerow, 2022).

Regional variations in RR were founded as important issue, since results shows a higher mortality risk in northern part of country. These differences might result from several factors, including different levels of exposure, demographic characteristics, or geographical, meteorological, or pollution factors (Anderson & Bell 2011). Physiological and behavioural adaptations of the local population also play a role in heat vulnerability (McGeehin & Mirabelli, 2001; Anderson & Bell, 2011; Sun et al., 2020). Belgrade and Novi Sad are more urbanized and effects of the urban heat island may modify risk. Cleland et al. (2023) showed that high urban heat island intensity areas account for 35% of the total heat-related cardiovascular burden, while low urban heat island intensity account for 4%. While urban communtiies cope with thermal comfort (Yin et al., 2023), it is important to note that adverse heat-related health outcomes are not merely an urban phenomenon. Rural residents are often more at risk during heat events than those in urban areas even after considering the urban heat island effect, built environmental factors, and population density (Fechter-Leggett et al., 2016; Jagai et al., 2017; Li et al., 2017). Mitigating the impact of heat on human health requires an all-hands-on approach to reduce vulnerability, particularly in the face of anthropogenic climate change which has already modified the duration, intensity, and spatial extent of heatwaves.

Limitations and Future Research

This study includes limitations and outlines potential areas for future research. Given the avaibility of data, the study only assesses heatwaves over a 16-year period, up through 2015. Thus, more recent heat events, which were characterized as more severe and intense (Ballester et al., 2023), were not included. Temperature data was based on a single location in each city, thus the results do not consider the small-scale variations in the urban heat island that are necessary to target intervention strategies. Other studies have showed temperatures within a community may differ substantially based on where one resides (Reid et al., 2009; Kim et al., 2017; Savić et al., 2018; Milošević et al., 2022). The results of this study are based on three cities in Serbia. In part, these locations were selected due to their large populations; the methodological approaches employed in this research rely on large population sizes for statistical testing. Heat is not merely an urban issue, however, and continued research as to how communiites, populations, and indiviuduals prepare, adapt, and respond to current and future heatwaves is needed, particularly in the face of anthropogenic climate change (Brown et al., 2020; Guardaro et al., 2022). Diverse approaches are needed to better contextualize heat impacts beyond the urban core (Tuholske et al., 2021; Mashhoodi & Kasraian, 2024). This is particularly important as communities around the world provide healthcare services to rural communities in spite of growing, urbanizing cores. Future research may build upon these results and assess the relationship with hospital admission data or evalaute heat perceptions within the community. Fewer studies explore morbidity data, in part due to the avaiability and ease of obtaining of such data.

Conclusion

This study shows that heatwaves increase the mortality risk, and heatwave characteristics, such as duration, seasonal timing, and intensity play important role in heat-related mortality. On average, early season, longer lasting, and more extreme heatwaves had a greater impact on mortality. Findings in this study could be useful and contribute to the development of a heat-watch warning system and improved communication as to the health hazard of heat may be future outcomes of this research, interlacing the government and non-government sectors who are interested in reducing heat-health disparities across Serbia.

Acknowledgements

This research was conducted, in part, as part of the 2023 U.S. Fulbright Scholars Program. The authors would like to thank the University of Novi Sad and Towson University for their institutional support. Also, the authors gratefully acknowledge the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Grants No. 451-03-66/2024-03/200125 & 451-03-65/2024-03/200125).

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